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Project #62: Casinova

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Abstract

The Casinova project presents the design and the implementation of an automated card dealer with the capabilities of 360-degree varying-distance dealing, as well as player detection and card identification. It integrates six subsystems: Control, Camera, Ejection, Swivel, Power, and Wi-Fi, to create a seamless automated dealing experience for players. An ESP32-S3 microcontroller serves as the brains of the machine and uses the OV2640 camera as well as a TOF distance sensor to detect both cards and player distances. These sensors are then used to swivel and eject cards at the correct distances. The stepper motors required for the build include a NEMA17 and NEMA11 stepper motor, as well as a 12V DC ejection motor. The stepper motors are driven by motor drivers, which allow easy maneuvering using the ESP32's code. The power required for the build includes power rails of the following voltages: 12V, 5V, 3.3V, 2.8V, and 1.2V. These rails are implemented using buck converters as well as LDO converters. The Wi-Fi is hosted on the ESP32-S3 chip itself and utilizes a backend server to host a webpage accessible from connected client devices. On the webpage is where users will put in their input and initiate the dealer's movements through the programmed logic on the microcontroller. The Casinova provides key features which are necessary for emulating a human dealer, as well as more features that only an outside entity in a game can provide, such as statistical analysis of each hand that is dealt. All these features make the Casinova a great machine for card game enthusiasts.

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1 Introduction

1.1 Problem

During the COVID-19 pandemic, when everyone was stuck indoors, there was an explosion in some of the more common household games involving a deck of cards. Games such as Spoons, BS, Egyptian Ratscrew, and Texas Hold 'em involve dealing a deck of cards to everyone in the game. With the increase in live stream viewers in professional poker, we see the need to try to emulate that professionalism at everyone's home games. With this experience comes having professionally trained dealers to keep the game progressing and having special-traced cards with compatible cameras to get the casino-like feel of recording your games. With cards having to be dealt in a specific order, it can be frustrating to play a game where the amateur game players are making mistakes often, preventing the entire table of players from enjoying the game at hand. Viewing casino live streams, all the information is given to you on a screen so you can follow along with the players at the table, but to emulate this at a home game, you need an expensive RFID deck of cards and a camera to view them. There is no product out there that is capable of providing statistical analysis to you using a regular deck of cards.

1.2 Solution

To emulate the experience of a live casino game paired with the excitement of viewing a live casino match, we plan to implement an automatic smart card-dealing machine. The machine, placed in the center of a table, will be capable of maneuvering 360 degrees around the table as well as dealing cards at variable distances to place them within arm's reach of the player. The dealer will feature a two-fold camera system, which has one camera facing outwards, detecting player location. Another camera will be pointed towards the underside of the deck, providing a video feed for the machine to detect card values, specifically the rank and suit of the card being dealt. With the card information, the machine will be able to verify the contents of a deck, as well as provide statistical information to players after hands. The cards will be dealt by two motors, one used to queue up cards to be dealt, and one to deal cards at variable speeds to satisfy our requirement for variable distance dealing. Players will be able to connect to the machine through their phones over Wi-Fi to input player action based on what game is being played. The machine will also relay hand analysis to players' phones during the match, with players being able to “sweat” out the table's hands.

1.3 High-Level Requirements

1. The dealer must distribute two cards to eight players in under 45 seconds with at least 99% accuracy to minimize misdeals.
2. The machine must identify all 52 unique cards in a standard deck to ensure deck integrity, prevent outside manipulation, and ensure fair gameplay.
3. The dealer must recognize player actions and respond accordingly, mimicking the function of human dealers, including the actions of dealing additional cards and advancing gameplay.
4. The dealer should provide statistical insights (odds, sweats, outs) to the player's external feed to enhance the viewing experience and provide strategic analysis to improve player skills.

2 Design

2.1 Introduction

Our final design for the Casinova is a fully automated card dealer capable of identifying cards, detecting players in real-time, and ejecting cards across variable distances both from the dealer and around the dealer. The Casinova uses real-time computer vision and motor control to detect and maneuver cards to the players, all of this running over Wi-Fi communication to streamline gameplay for end users.

The block diagram in Figure 1 indicates that the overall system is divided into six subsystems, those being the Control, Camera, Ejection, Swivel, Power, and Wi-Fi subsystems. The Control Subsystem is the main brain of the machine, responsible for interpreting image data from the Camera Subsystem, receiving player input from the Wi-Fi subsystem, and controlling the motor actions across the Ejection and Swivel Subsystems. The Power Subsystem is in charge of supplying the correct voltages to each of the voltage rails.

During the development of the Casinova, we made a few changes to the block diagram, which included an addition of an LED to the Camera Subsystem to illuminate the card as we took an image of it, as well as the addition of two extra voltages which were required for the Power Subsystem (2.8V & 1.2V). These voltages were necessary for the Camera Subsystem to work properly.

Performance-wise, the project met several quantitative benchmarks. One benchmark that was completed was the ability to detect an accurate suit/rank for every card in the deck, which was tested thoroughly once the card recognition code was debugged. Another benchmark that was completed was our ability to maintain Wi-Fi responsiveness between client and server devices, where latency between the devices was well under 150ms.

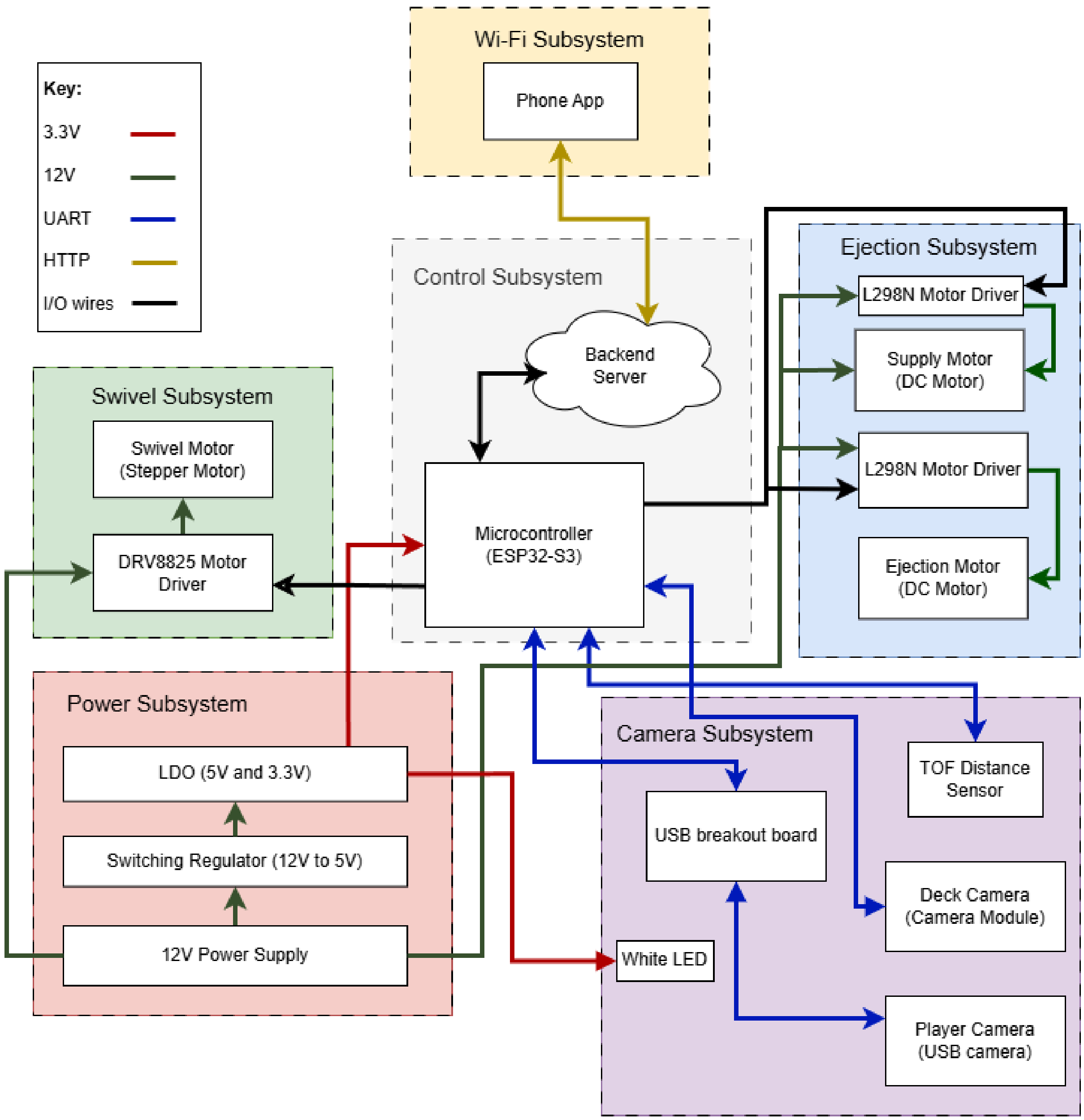

Figure 1: Block Diagram of the Casinova

2.2 Design Details

The Casinova consists of six subsystems. Below, each subsystem is described in component-level design.

2.2.1 Control Subsystem

The control subsystem includes an ESP32-S3 microcontroller, specifically the ESP32-S3-WROOM-1-N16R8, which comes with key components such as 16 GB of Flash Memory and 8 GB of PSRAM. These specifications were especially important, as we needed more memory to store both the camera images in PSRAM as well as the libraries for image processing in the Flash memory.

The other key component of the Control Subsystem was the inclusion of the Backend Server which was able to be hosted on the ESP32. With our specific microcontroller, we were able to communicate over Wi-Fi protocol to have outside devices connect to the microcontroller and interact with it by sending I/O HTTP packets. With the backend server able to be accessed by client devices, these instructions would be sent through the microcontroller and would be converted to signals for the other subsystems.

2.2.2 Camera Subsystem

The camera subsystem encapsulates all the sensors that detect environment variables to determine what actions to take next. These sensors include

- OV2640 Camera
    - Used for the image capture of cards queued up within the machine.
    - Connected directly to the microcontroller through PCB and is powered by the following voltages
        - 3.3V for I/O
        - 2.8V for analog circuitry
        - 1.2V for digital circuitry
    - Provides a QVGA (320 x 240) resolution image of the corner of the queued playing card, and sends the image data to the Control Subsystem for image processing.
    - Utilizes an LED to illuminate the queued card for better exposure
- USB 1MP Camera
    - Used for taking images of the frontal environment of the machine. Takes pictures which are processed to determine whether a player is directly in front of the machine or not.
    - Sends the captured image to the control subsystem for image processing
- TOF10120 Distance Sensor
    - Time of Flight laser sensor which is used to determine how far an object in front of the machine is

- Sends constant distance data over the Serial port to the Control Subsystem
- Used to calculate the speed at which the Ejection Subsystem ejects cards.

2.2.3 Ejection Subsystem

The ejection subsystem is responsible for shooting out the cards from the console to the player. All the parts for this subsystem include:

- DRV8825 Motor Driver
  - This was used to take information from the ESP32-S3 to tell how many steps to send to the stepper motor
  - We can control the degrees of rotation and the speed of the cards that are supplied to the DC motor.
- NEMA11 stepper motor
  - This stepper motor gave us enough precision to start and stop at a certain number of degrees.
  - This meant that we were able to control how far the cards needed to be pushed forward before the cards got caught by the DC motor.
- L298N Motor Driver
  - This motor driver is used to control the speed of the DC motor by supplying it with a PWM signal from the ESP32
  - This motor driver communicates with the ESP32 and the DRv8825 chip to provide the casing with an “algorithm” to eject one card at a time.
- Gikfun Miniature DC Motor
  - This is the DC motor that was in use for ejecting the cards to the user.

2.2.4 Swivel Subsystem

The swivel subsystem is responsible for turning our dealer clockwise and counter-clockwise. This subsystem communicates with the camera subsystem and will stop with the machine when the camera and the ESP32 see a person right in front of it. The parts for this subsystem include:

- DRV8825 Motor Driver
  - This was used to take information from the ESP32-S3 to tell how many steps to send to the stepper motor
  - We can control the degrees of rotation and the speed of casing to avoid skipping that would be caused by the downward pressure of the case
- NEMA17 stepper motor
  - This stepper motor gave us enough precision to start and stop at a certain number of degrees.
  - This meant that we were able to control the degree of angle we wanted to rotate the case by. We chose 1.8 degrees but we could have chosen as small as 0.05625 degrees

2.2.5 Power Subsystem

The power system is responsible for powering the entire dealer using a 12V, 2A power supply. We chose this because we knew that to control all our motors, we needed at least 2A. The power subsystem also needs to supply 12V, 5V, 3.3V, 2.7V, and 1.2V to all the various applications of our project. The parts of this subsystem include:

- LM7905
  - This is our 12-5V switching regulator. This takes in a 12V input and outputs 5V
- AMS1117-3.3
  - This is our 3.3V LDO. This takes in a 5V input and outputs 3.3V to our ESP32 which is responsible for powering the control subsystem
- XC6206P272MR-G
  - This is our 2.7 LDO. This takes in a 3.3V input and outputs a 2.7V to our camera subsystem
- XC6206P122MR-G
  - This is our 2.7 LDO. This takes in a 3.3V input and outputs a 1.2V to our camera subsystem

2.2.6 Wi-Fi Subsystem

The ESP32-S3's built-in Wi-Fi module was used to enable communication between the machine and client devices. The built-in module operated at 2.4 GHz with Access Point mode enabled. This would allow maximum compatibility with most devices. The backend of the subsystem was implemented using the ESPAsyncWebServer and AsyncTCP libraries. These libraries allowed for asynchronous actions to occur between the Casinova and client devices, especially useful for inputs such as player action.

3 Design Verification

3.1 Control Subsystem

The testing of the control subsystem included a variety of different requirements which we felt would demonstrate complete functionality of the control subsystem. These requirements can be found in Appendix A's Table 1: Control Subsystem.

1. Boot and initialize the backend server when the system is powered on
    a. Verified by accessing the hosted website after plugging in the PCB
2. Power on/off motors of the dealer, as well as keep the rotation position of the dealer
    a. Verified by confirming ejection motor spins when told to
    b. The rotational position of the swivel motor is controlled by internal code and tracked from the initial starting orientation
3. Interpret images of cards to determine the suit and rank of a card
    a. Verified by loading in all 52 cards of a standard Bicycle deck of cards, and processing images of the suit and rank of every card successfully.
4. Interpret images of the machine's frontal environment to determine if there is a person or not
    a. Was not verified to work, as we did not find a need for the frontal camera nor the person-detection code.
    b. The frontal camera was not implemented into the final design of the machine.

3.2 Camera Subsystem

The testing of the camera subsystem included a variety of different requirements which we felt would demonstrate complete functionality of the camera subsystem. These requirements can be found in Appendix A's Table 2: Camera Subsystem.

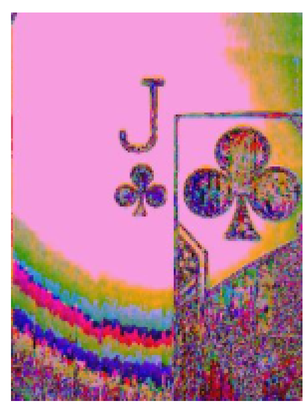

Figure 2: OV2640 Camera Output

1. Send clear image feed of a queued card within the machine
    a. Verified by taking contents of the OV2640 frame buffer and displaying it on a computer (Figure 2)
2. Must illuminate a queued card when a photo is being taken
    a. Verified by utilizing an LED that stays on while the machine is powered.
3. Must send a clear image feed of players in front of the machine
    a. Was not verified to work, as we did not implement the frontal camera.
4. Must send constant distance information to the control subsystem
    a. Verified to work in early testing, but was unable to work with the final design

3.3 Ejection Subsystem

The testing of the ejection subsystem included a variety of different requirements which we felt would demonstrate the complete functionality of the ejection subsystem. These requirements can be found in Appendix A's Table 3: Ejection Subsystem.

1. The ejection system must be capable of delivering a card to a player seated at varying distances from the machine.
    a. Verify that the card is delivered to players at different distances 50cm, 100cm, and 150cm by setting up a ruler and testing the ejection distance
    b. Confirm that the duty cycle decreases as player distance increases and that the ejection motor RPM reduces in proportion to the duty cycle changes by measuring the RPM outputted from the DC motor
2. The ejection system must be able to transmit card information to the Wi-Fi subsystem.
    a. Confirm that the RPM of the supply motor is at a speed that the camera can read the card with 100% accuracy by loading the machine with the entire deck and making sure there are no errors when reading the cards
    b. Ensure that Wi-Fi communication doesn't delay the ejection process by testing the speed of the ejection process before adding the camera module and after
3. The ejection system must detect potential errors (such as jams) and notify the user accordingly
    a. Intentionally create card jams and ensure that the system halts on the operation signals an error and relays the error codes to the user with information on which motor is the cause of the jam
    b. Create an easy-to-reach access point to allow the user to clear the jam without taking the machine apart

3.4 Swivel Subsystem

The testing of the swivel subsystem included a variety of different requirements which we felt would demonstrate the complete functionality of the swivel subsystem. These requirements can be found in Appendix A's Table 4: Swivel Subsystem.

1. The swivel system must enable precise 360° bidirectional rotation from its initial orientation with positional accuracy.
    a. Marking the starting position on the motor shaft and visually confirm it completes a full 360 degrees clockwise and counterclockwise
    b. Test rotations at different speeds to ensure that accuracy is maintained throughout the entire 360-degree motion
2. The swivel system must halt rotation immediately upon detecting human presence via integrated camera input.
    a. Sit a person down and see if the system can stop rotating with the front of the machine facing the person
    b. Verify that the motor will resume rotation when a player has removed themself from the table

    c. Sit multiple people down and see if the system can stop and continue rotating after each person is detected
3. The swivel system must maintain absolute positional awareness relative to its origin and retain orientation through a mechanical locking mechanism, even during power loss.
    a. The machine can rotate to a specific angle at the table with the front of the ejection subsystem being 0 degrees
    b. Test the position retention by manually rotating the motor when powered off and verifying that it returns to the original position when powered back on

3.5 Power Subsystem

The testing of the power subsystem included a variety of different requirements which we felt would demonstrate complete functionality of the power subsystem. These requirements can be found in Appendix A's Table 5: Power Subsystem.

1. The power subsystem provides 12V, 5V, and 3.3V to the entire system through a single source
    a. Connect the 12V power supply to the Switching Regulator, and confirm 5V is sustained while powered
    b. Connect the 5V from the Switching Regulator output to the Dropout Regulator, and confirm that 3.3V is sustained while powered

3.6 Wi-Fi Subsystem

The testing of the wi-fi subsystem included a variety of different requirements which we felt would demonstrate complete functionality of the wi-fi subsystem. These requirements can be found in Appendix A's Table 6: Wi-Fi Subsystem.

1. Must be able to send data to a specific Wi-Fi network from the dealer
    a. Utilized the AP (Access Point) mode on the ESP32's Wi-Fi module to allow client connections to the microcontroller
    b. Verified data transmission by loading a microcontroller-hosted webpage on a client device
2. Achieve a consistent data transmission rate of at least 1 Mbps
    a. Verified by loading the webpage and all of its assets almost instantaneously on connection to the microcontroller.
3. Data packets sent from ESP32 should not exceed 150ms to fulfill real-time responsiveness.
    a. Verified through input/output tests with webpage buttons controlling motors.
    b. Found that our responsiveness was below 100ms for 95% of our actions when both the client and the Casinova were in optimal Wi-Fi conditions.

4 Costs

4.1 Parts

When it comes to parts, a list of the necessary parts can be found in Figure 4.1.0.

Part Name	Subsystem	Price	Notes
1MP Camera Module Horn Lens W202012HD	Camera	$8.00	Gets here on time
USB-A Breakout Board (Cheaper)	Camera	$5.39	Cheaper option (x10)
FFC FPC Connector Board 24 Pin 0.5mm Socket to 2.54mm	Camera	$9.99	OV2640 Connector (Breadboard Demo)
ESP32-S3-DevKitC-1-N8R8	Control	$19.00	ESP32-S3-WROOM-1
Motor Driver Controller Board x2	Ejection	$6.99	3 drivers, but each board comes with 2
WWZMDiB A4988 Stepper Motor Drive	Swivel	$7.99	Motor Driver for NEMA17 Stepper Motor
OV2640 Camera 160°I2C	Camera	$9.99	Camera Deck Validation
TOF10120 Time-of-Flight Distance Laser Distance Measuring Sensor	Camera	$19.00	TOF needed to have a wider range the commerical use
LM2931AZ-5	Power	$1.11	12v - 5v Conversion (PCB)
LD1117S33CTR	Power	$0.32	5v to 3.3v Conversion (PCB)
ESP32-S3	Control	$3.35	Microcontroller (PCB)
ABM8-24.000MHZ-R60-D1W-T	Camera	$1.00	Crystal Oscillator (24.0MHz) (PCB)
WWZMDiB 3 Pcs Stepper Motor Driver Module	Swivel	$8.99	Stepper Motor Drivers
STEPPERONLINE Nema 17 Stepper Motor Bipolar 2A	Swivel	$13.99	Stepper Motor
Greartisan DC 12V 550RPM Gear Motor High Torque Electric Micro Speed Reduction Geared Motor	Ejection	$14.99	DC Motor with Encoder

Figure 4.1.0: Parts List for the Casinova

The total cost for parts ended up being $130.10

4.2 Cost of Labor

We can expect a salary of $40/hr × 40 hr × 16 weeks = $25,600 per team member. We need to multiply this amount by the number of team members, $25,600 × 2 = $51,200 in labor cost.

5 Conclusion

5.1 Accomplishments

We accomplished many things in our project. We were successful in taking an idea of shooting cards, putting in no a breadboard, and finalizing our idea into a functional product. Creating many subsystems and then working in modules and coming together to make everything work was a challenge for our group, but we were able to make it work. This was our group's first time creating a PCB, so getting to design and order our first PCB and have it working was an accomplishment. Soldering a PCB was another challenge for us. We had to order many extra parts because we didn't end up choosing the right footprints for the PCB for the first time.

5.2 Uncertainties

One of our uncertainties for our project that we didn't get working and didn't know if it was possible working with our current design is our camera subsystem. This is because it was extremely difficult to get our card detection working because of memory space, and based on our original design of our project, we wanted to get player detection working. We would need to add an extra memory module in order for our detection algorithm to work. We found out very early on in our project that working with cameras was a very difficult module to work with. Another uncertainty that we had was to ensure that our ejection steps would result in less jams in our current design. Right now, our project jams up about 1 in every 5 cards, we would love to increase this ratio so that the percentage of jams in our system would decrease. Because we aren't mechanical engineers, this was an uncertainty for our current design that we would love to work on more after this semester.

5.3 Ethical considerations

There are many ethical considerations from the project that we made. Because our final project used a TOF distance sensor, this means that there are lasers in our project. We have to be careful about dealing with lasers, as the IEEE Code of Ethics Section I.1 states "to hold paramount the safety, health, and welfare of the public" [1]. A laser mounted onto a moveable object provides an issue with the subjects potentially moving it while in use. At the start of the project, we found that we wanted a camera in the front to take pictures of the players and use player detection. With our product shooting cards out at some high speed, there is some danger that we need to take with some concern. The ACM Code of Ethics, section 1.1 states that any product is to "minimize negative consequences of computing, including threats to health, safety, personal security, and privacy" [2]. With further testing, we found a range of our motors that would safely eject cards at a speed where it won't hit the players. Even after further testing, there is still an inheritance risk for the players to get hurt from the cards. Proper notice and documentation would be required to minimize the risk for the players.

5.4 Future Work

Future work for the Casinova includes a multitude of different features. Initially, future work would include work on the Camera Subsystem, specifically making the TOF distance sensor as well as the OV2640 camera work in the first place. After all the initial criteria for the project is met, we'd then pivot to replacing the website app with a bluetooth phone app. This would allow a more seamless integration of client inputs for our product, as they would not be bogged down by their Wi-Fi connection, but rather their Bluetooth connection. Bluetooth connection is much more reliable. In addition to the phone app, we'd love to increase the speed and precision of the Casinova. A higher degree of speed and precision would be achieved by finding better parts for our machine and also redesigning the physical casing to be smaller and lighter. Looking into the future for our project, we'd thought that an AI competitor (CPU) would be a great addition, especially at home games where there might not be enough people to play a game, or in training situations, where you would want to practice your play and compete against an intelligent machine. Finally, we'd integrate stronger security features into the backend server which our machine hosts, as cheating may be possible if certain users are able to get the card information which the machine houses. Overall, we are happy with the work we were able to get done, but there is a lot more we would love to accomplish with the Casinova project

References

[1] IEEE, “IEEE Code of Ethics,” *ieee.org*, Jun. 2020.

https://www.ieee.org/about/corporate/governance/p7-8.html

[2] Association for Computing Machinery, “ACM code of ethics and professional conduct,” *Association for Computing Machinery*, 2018. https://www.acm.org/code-of-ethics

Appendix A: Requirements and Verification Table

Table 1: Control Subsystem - Requirements & Verification

Requirements	Verification	Verification Status (Y or N)
The Control Subsystem must be able to boot and initialize its backend server when the system is powered on.	● Power on the ESP32-S3 and ensure that the backend server initializes and begins executing its main loop ● Verify through serial debugging that system logs confirm successful initialization.	Y
The Control Subsystem must be able to power on/off the motors of the dealer, as well as keep track of the rotational position of the dealer.	● Connect the motor driver to the ESP32-S3 and control the motors to start and stop using the ESP32's GPIO pins. ● Utilize the distance information from the Camera Subsystem to power on the ejection motor to a certain degree to eject cards the correct distances so they land in front of players ● Keep track of the rotational position of the machine by storing rotational data and updating rotational data as the machine changes direction ● Be able to send output signals synchronously so that the actions of the motors do not interfere with each other	Y
The Control System must be able to interpret images of cards to determine the value (suit & rank) of the card.	● Take in the image data from the Camera Subsystem and interpret the rank and suit of the currently queued card ● Store the information of logged cards as reference data for future user actions	Y
The Control System must be able to interpret images of its frontal environment to determine whether	● Take in image data from the Camera Subsystem of the front-facing camera and interpret if a person is in front of the machine or not ● Signal rotational motors to start when there is	N

Requirements	Verification	Verification Status (Y or N)
there is a person in front of it or not	no one detected in front of the machine, and to stop and deal out a card when there is someone detected in front of the machine ● Keep track of rotational position, and make sure to reset rotation by spinning in the opposite direction to reduce torsion load on inner wires	

Table 2: Camera Subsystem - Requirements & Verification

Requirements	Verification	Verification Status (Y or N)
The Camera Subsystem must be able to send a clear image feed of a queued card within the machine.	● Hook up the pins of the OV2640 camera to the ESP32-S3 microcontroller. ● Under normal operating conditions, relay camera data back to the microcontroller with the DVP protocol	Y
The Camera Subsystem must be able to illuminate a queued card when a photo is being taken.	● When an image is requested, send a 3.3V pulse through the LED to illuminate the card. ● Ensure that the LED is lit for at least double the amount of time that the camera requires to capture a photo	Y
The Camera Subsystem must be able to send a clear image feed of players in front of the machine.	● Hook up the pins of the USB Camera to the ESP32-S3 microcontroller ● Relay camera data back to the microcontroller with the UVC protocol	N
The Camera Subsystem must be able to send a constant information feed regarding the distance of an object in front of the machine (up to 180cm away).	● Hook up the pins of the TOF10120 sensor to the ESP32-S3 microcontroller ● Under normal operating conditions, be able to detect between 5-180 cm distances of players sitting in front of the machine ● Relay that information to the microcontroller as raw data bytes.	N

Table 3: Ejection Subsystem - Requirements & Verification

Requirements	Verification	Verification Status (Y or N)
The ejection system must be able to eject a card to a player sitting a variable distance away from the machine.	• Verify that the card is delivered to players at different distances 50cm, 100cm, and 150cm • Confirm that the duty cycle decreases as player distance increases and that the ejection motor RPM reduces in proportion to the duty cycle changes	N
The ejection system must be able to communicate with the Wi-Fi subsystem with the card information	• Confirm that the RPM of the supply motor is at a speed that the camera can read the card with 100% accuracy • Ensure that Wi-Fi communication doesn't delay the ejection process	Y
The ejection system must be able to deal with potential errors (such as jams) and relay the information to the user	• Intentionally create card jams and ensure that the system halts on operation and signals an error • Relay the error codes to the user with information on which motor is the cause of the jam • Create an easy-to-reach access point to allow the user to clear the jam without taking the machine apart	Y

Table 4: Swivel Subsystem - Requirements & Verification

Requirements	Verification	Verification Status (Y or N)
The swivel system must be able to rotate 360 degrees from its starting orientation in an accurate manner in both a clockwise and counterclockwise manner	● Marking the starting position on the motor shaft and visually confirm it completes a full 360 degrees clockwise and counterclockwise ● Test rotations at different speeds to ensure that accuracy is maintained throughout the entire 360-degree motion	Y
The swivel system must be able to stop the rotation when a person is detected by the camera subsystem	● Sit a person down and see if the system can stop rotating with the front of the machine facing the person ● Verify that the motor will resume rotation when a player has removed themself from the table ● Sit multiple people down and see if the system can stop and continue rotating after each person is detected	N
The swivel system must be able to accurately track its current position relative to the starting orientation and maintain its position when not actively rotating (even when power is removed)	● The machine can rotate to a specific angle at the table with the front of the ejection subsystem being 0 degrees ● Test the position retention by manually rotating the motor when powered off and verifying that it returns to the original position when powered back on	Y

Table 5: Power Subsystem - Requirements & Verification

Requirements	Verification	Verification Status (Y or N)
The power subsystem must be able to regulate and provide the following voltages (12V, 5V, 3.3V)	● Connect the 12V power supply to the Switching Regulator, and confirm 5V is sustained while powered ● Connect the 5V from the Switching Regulator output to the Dropout Regulator, and confirm that 3.3V is sustained while powered	Y

Table 6: Wi-Fi Subsystem - Requirements & Verification

Requirements	Verification	Verification Status (Y or N)
The ESP32 must be able to send data to a specific WiFi network from the dealer	● The ESP32-S3 can establish a connection to a known Wi-Fi network using the IoT Development Framework ● Send a set of predefined sample data packets to the server on the network and repeat this process to ensure consistency	Y
The subsystem should achieve a consistent data transmission rate of at least 1 Mbps which is enough for a video feed	● Set a continuous data stream from the ESP32 server to the network and use a network monitoring tool such as WireShark to measure the data transmission rate ● Repeat this test for an hour to ensure consistency ● Calculate the average transmission rate and verify that it meets the 1 Mbps requirement, +/-5%	Y
Data packets sent from the ESP32 should not exceed 150ms to fulfill a real-time responsiveness	● Implement a ping-pong test between the ESP32-S3 Station and the server to measure the round-trip time of each packet ● Verify that 95% of the packets have a round-trip time of less than 150ms	Y